NL-eEDM

Update for Nikhef Scientific Advisory Committee

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Nikhef
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VU VRIJE UNIVERSITEIT AMSTERDAM

UvA

The NL-eEDM program

Use molecular enhancement to probe the electron's electric dipole moment

'Symmetry-violating properties of fundamental particles can add minuscule but measurable perturbations to the energies of molecular states' (Udrescu et al, Nature Physics 2023)

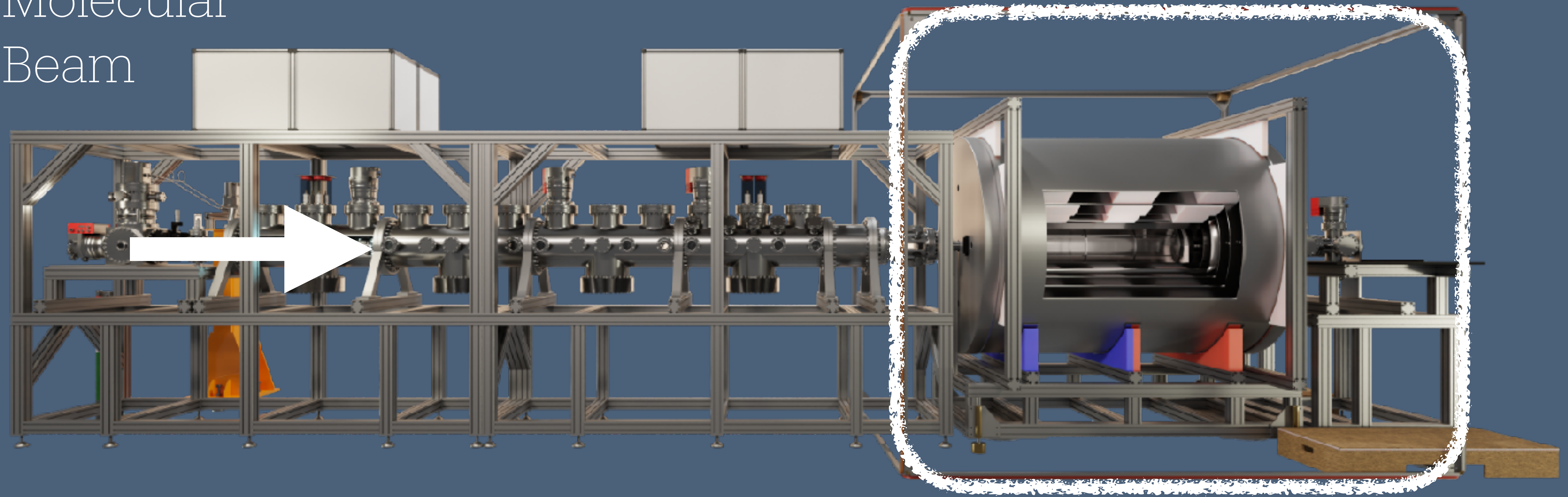


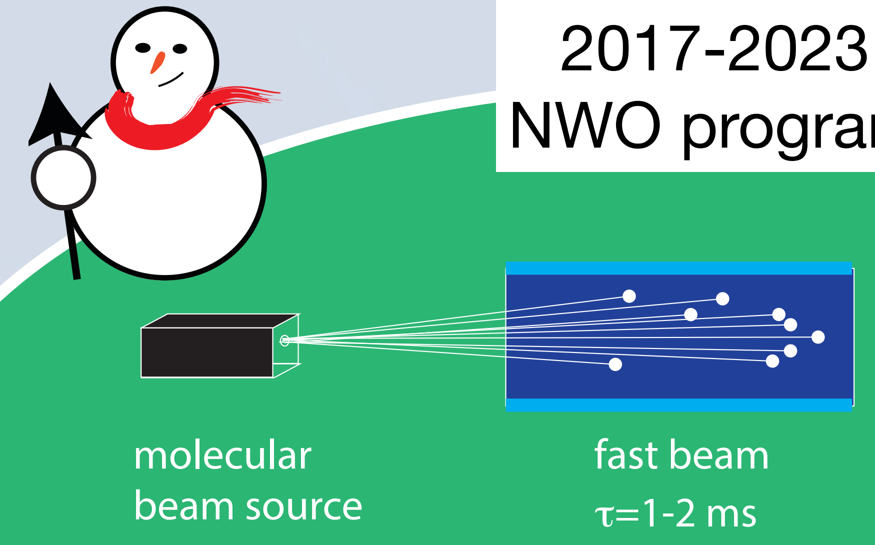
Table-top precision tests

New experimental approaches to study fundamental physics

NL-eEDM: Hendrick Bethlem, Anastasia Borschevsky, Steven Hoekstra, Steven Jones, Rob Timmermans, Wim Ubachs, Jordy de Vries, Lorenz Willmann

Measure the electron’s electric dipole moment using cold molecules

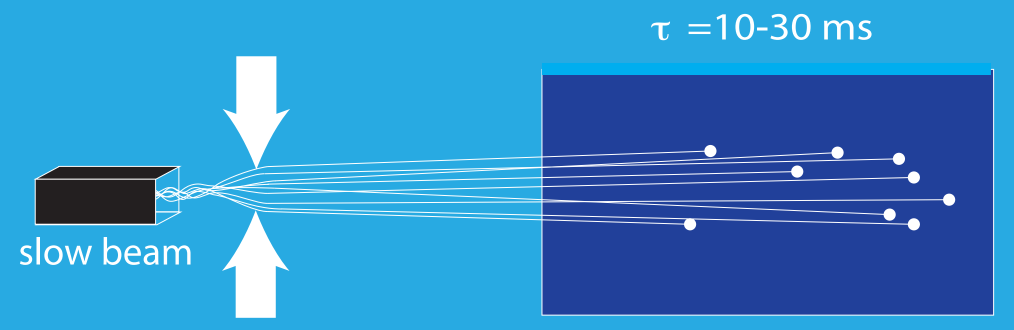
2017-2023
NWO program



Phase 1
Fast beam of BaF molecules

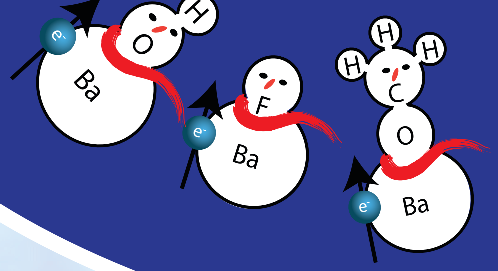
2023-2028
ENW-XL

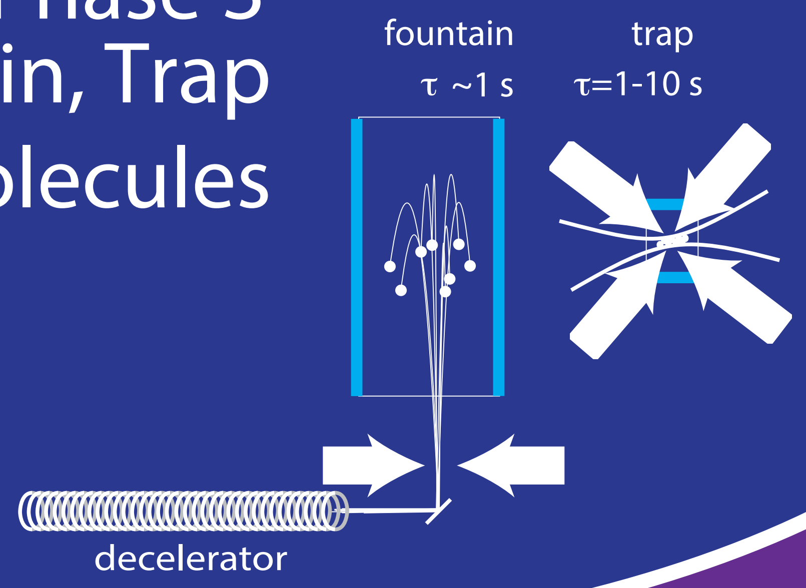
Phase 2
Slow and cold molecular beam



2023-2028
ENW-XL, M2 and VICI

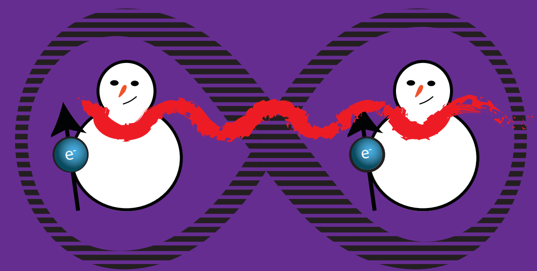
Phase 3
Fountain, Trap
Better molecules





2025-2035

Phase 4
Beyond the quantum limit



Minimize statistical uncertainty

$$S \propto \frac{1}{E\tau\sqrt{N}}$$

Heavy polar molecules give a high sensitivity to new physics

Slow and cold beams provide a long interaction time

Using entanglement enables linear scaling with the number of molecules

Control systematic effects

Demonstrate an all-optical superposition state creation

Slow beams push magnetic field senstivity to the limit

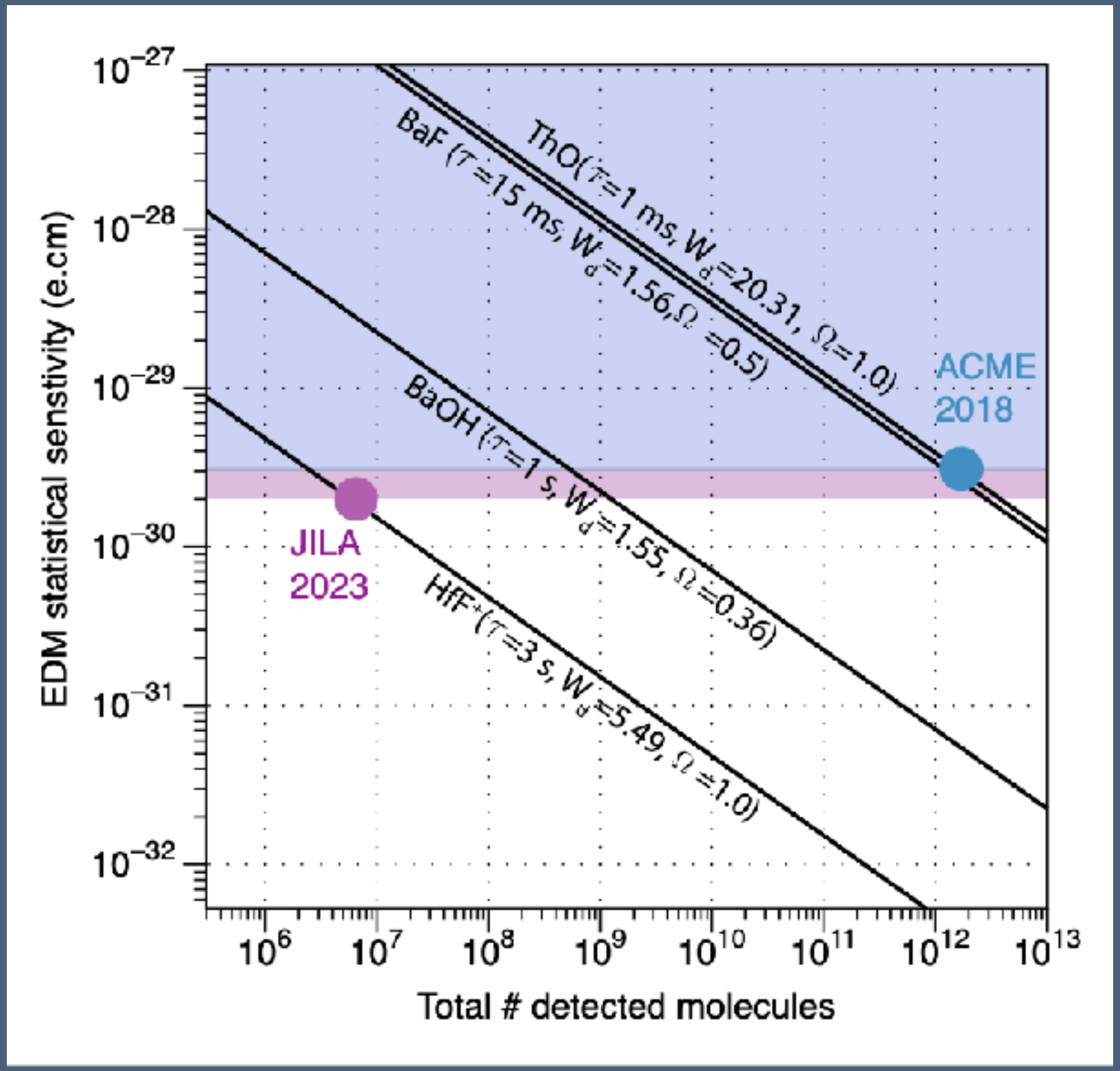
Polyatomic molecules provide co-magnetometer states

Theory framework: connect eEDM experiments to high-energy particle physics

Main achievements in eEDM experiment

Phase 1 (fast beam): completed

- Completed first full cycle of eEDM experiment (concept, design, construction, commissioning)
- Developed new approach to evaluation of systematics
- 6 hours data (~10^6 detected molecules) gives limit of eEDM < 0.8 (1.8) 10^{-25} e-cm, as expected



Bause, Hoekstra et al (ArXiv2411.0044)

Phase 2 (slow beam): underway

- More and slower molecules, higher E-fields, better detection
- Now at stage of integration of beam & interaction zone
- Current experimental team: 4 PhD + 1 postdoc
- aim: 5 10^{-30} e-cm with 5 10^{12} detected molecules

Phase 3 (trapped molecules): developing

- new BaOH source operational, decelerator (re)built
- further cooling and trapping under development
- current team: 5 PhD expt @ RUG, 1 PhD @VU
- aim: 1 10^{-30} e-cm with 5 10^9 detected molecules

The team

Staff:

+ Experiment: Steven Hoekstra, Lorenz Willmann, Steve Jones @ RUG, Rick Bethlem @ VU/RUG
+ Theory: Anastasia Borschevsky @ RUG, Jordy de Vries @ VU
+ Wim Ubachs @ VU, Rob Timmermans @ RUG in advising roles
+ 2 research technicians. Recently new position opened, 3 years financially supported by Nikhef

- Teaching, management and other research tasks at University limit effective research time

PhDs and postdocs:

Formed teams around phase 2 and phase 3 experiments, and theory

Phase 2: 4 PhD + postdoc

Phase 3: 5 PhD @Groningen, 1 PhD @Amsterdam VU

Theory: 1 PhD + 2 postdoc @Groningen, 1 PhD @Amsterdam UvA

Current PhD/postdoc level is good - challenge to obtain grants to maintain this level

Example ongoing projects

Scientific

Phase 2:

What is the optimal eEDM readout scheme for the slow beam with significant velocity spread?

Can we use multiple electronic transitions in BaF to emit multiple photons/molecule?

Phase 3:

What is the optimal pathway to cool BaOH molecules into the (010) eEDM state?

What is the most efficient way to bring molecules from the decelerator into an optical trap?

Technical

Coupling the cryogenic laser-cooled beam to the interaction zone

Detecting IR photons with high solid angle, quantum efficiency and low background

Optimal photon collection for dispersed fluorescence

Building an optical trap with 10^8 optical polarisation purity

Future plans, funding, opportunities and challenges

+ We have a clear research path, built along phases, with a strong team in place

+ Intensify collaboration with international eEDM teams: advantage of scale.
  build on our molecule cooling expertise, quantum structure know-how and interpretation, and our position within Nikhef

+ Continue increased use of Nikhef technical support (computing, mechanical, electronics)

+- Need to keep applying for grants to maintain current level of PhDs and postdocs

- Dedicated scientific staff to the experiment is minimal for our ambitious program

Relation to other Nikhef programs/activities

R&D group: common interest in development of quantum sensors for new physics
molecule detection, IR photon detection, fast quadrant photodiodes, optical traps

Gravitational waves: connections on optical cavities and fast feedback systems

Dark Matter: background reduction and DAQ techniques

ML/AI: chance to use neural networks for optimisation of our experimental setups,
with unique possibilities at our scale of experiments - but requires manpower

Theory: crucial, this is an integral part inside of our research program

LHCb: overlap on conceptual level and data-analysis techniques

ATLAS: possibly data-acquisition hardware